Army risk assessment modeling system for evaluating health impacts associated with exposure to chemicals

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Abstract

The Army Risk Assessment Modeling System (ARAMS) is a computer-based, knowledge delivery, and decision support system that integrates multimedia fate/transport, exposure, uptake, and effects of chemicals to assess human and ecological health impacts and risks. ARAMS is being developed to: reduce the time and cost for conducting site-specific health risk assessments; provide more uniform methods for conducting risk assessments with more reliable risk estimates; and reduce the cost of remediation by establishing more reasonable cleanup targets. ARAMS is based on the risk assessment paradigm of combining exposure and effects assessment to characterize risk. ARAMS uses the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES) for the system main chassis. FRAMES is a modular modeling framework that allows seamless linkage of disparate models and databases. ARAMS contains various tools needed for risk assessment, such as viewers, report generators, and a module for assessing uncertainty. ARAMS allows for both screening-level and focused (i.e., comprehensive) assessments and has linkages to Web-based databases to allow the use of up-to-date information for conducting risk assessments. ARAMS is being fielded in stages with new versions released approximately annually. Although the primary focus of ARAMS development is associated with models and methods for assessing contaminant exposure and effects on military ranges and bases, it is generally applicable to any setting with contaminated sources or media.

1 Introduction

U.S. Department of Defense (DoD) operations of munitions plants, bases, training ranges, and other facilities have resulted in the release of chemicals, military relevant compounds (MRCs), and other contaminants to soil, groundwater, surface water, and air. The risks to both human and ecological health associated with multimedia exposure to these compounds must be evaluated. The U.S Army utilizes risk assessment procedures to determine cleanup target levels and to evaluate remediation alternatives to provide the most cost-effective approach to reach these levels. Currently, risk assessment procedures are plagued by high levels of uncertainty in both the estimate of effects of the contaminants as well as the probability of exposure. This uncertainty results in excessively conservative risk estimates and levels of cleanup, driving the cost of the cleanup to prohibitive levels.

The U.S. Army Engineer Research and Development Center (ERDC) is developing a computer-based, knowledge delivery, and decision support system that integrates multimedia fate/transport, exposure, uptake, and effects of chemicals to assess human and ecological health impacts and risks. The Army Risk Assessment Modeling System (ARAMS) is based on the widely accepted risk paradigm, where exposure and effects assessments are integrated to characterize risk. The development of ARAMS is expected to significantly reduce the time required to conduct risk assessments, thus, significantly reducing cost. Additionally, substantial cost savings for cleanup are expected by reducing the influence of uncertainty in setting cleanup targets. ARAMS is an ongoing development that is being accomplished in phases. This paper discusses developments for version 1.0 and presents an example application.

2 Development description

The overall strategy for ARAMS development is to build the system in stages, with lower-order (i.e., screening-level) assessment features included first, then higher-order (i.e., comprehensive or more focused) assessment features included later. Screening-level methods involve the use of simpler, analytical models or models of limited dimensions for exposure assessment. Such models or methods make simplifying assumptions that reduce data requirements and time and effort to apply. The comprehensive assessments will involve the use of more complex, numerical exposure models that are often multi-dimensional and involve more detail, but require more data, time, and effort to apply while yielding more information. Higher-order methods may also involve more comprehensive methods for assessing effects, such projections of ecological populations, whereas hazard quotients are used now. ARAMS 1.0 features only the lower-order capabilities, whereas later versions will feature higher-order methods.

2.1 System framework

The development strategy also features the use of an object-oriented, system framework to construct environmental pathways and exposure routes and to link various models or databases for exposure and effects. The system framework is based on the Framework for Risk Analysis in Multi-media Environmental System (FRAMES) [1] developed by Battelle Memorial Institute, which operates the Pacific Northwest National Laboratory (PNNL) of the U.S. Department of Energy. FRAMES enables the user to specify, through objects, the pathways and risk scenarios and to choose which particular model or database to use for each object. New models, databases, or methods can be added to FRAMES objects (i.e., modules) as long as the new model/database/method consumes and produces the type of information characteristic for the module. During the course of ARAMS development, modifications were made to FRAMES to allow new types of modules, such as ecological exposure and effects.

2.2 Modules

ARAMS/FRAMES contains the following modules:

- database for chemical-specific physicochemical properties, bioaccumulation factors, and human health effects;
- source terms for describing initial contaminant concentrations or release characteristics;
- fate/transport modules for air, surface water, soil-vadose zone, and groundwater;
- human exposure pathways;
- human receptor routes;
- human health impacts assessment;
- ecological effects databases;
- ecological exposure pathways;
- ecological health impacts assessment;
- sensitivity and uncertainty analysis; and
- GIS.

Each module can host multiple models, methods, or databases to accomplish module objectives. For example, there are several models/methods hosted within the Source Term Module, such as computed source term release and known soil and water concentrations, from which the user can select the model most appropriate for their application.

The sensitivity and uncertainty module uses Monte Carlo analysis with Latin Hypercube sampling and user specified distributions for stochastic parameters. The GIS module is still under development. Microsoft Excel-based plotting packages are provided for each module. A report generator for the risk assessment guidance for Superfund (RAGS) is also available for reporting results in a form that is compatible with existing procedures.

2.3 Models and databases

All the models within ARAMS/FRAMES modules at this time can be classified as screening-level models. There is a suite of models within the system referred to as MEPAS (Multi-media Environmental Pollutant Assessment System) [2]. MEPAS provides models for: sources; fate/transport in air, streams, vadose zone, and groundwater; exposure pathways for water, air, soil, crops, fish, and farm animals; human uptake routes; and human health impacts. The MEPAS fate/transport models are typically analytical solutions to simplified transport equations, such as one-dimensional advection with three-dimensional diffusion. Other models have been added to the system, such as the surface water, contaminant fate model, RECOVERY [3], the Hydrologic Evaluation of Lechate Production and Quality (HELPQ) [4], a model for theoretical bio-accumulation potential (TBP) for estimating aquatic species uptake [5], and a Wildlife Ecological Assessment Program, WEAP [6], for computing ecological health impacts. A Terrestrial Wildlife Ecological Model (TWEM) is being added during 2002 to compute exposure doses for terrestrial species. There are plans to bring other screening-level models into the system, and work is underway to ling to comprehensive models, such as those in the Groundwater Modeling System (GMS) [7]. The GMS is a modeling environment for 3D, numerical subsurface/groundwater flow and reactive transport models. It should be noted that there are also input screens for entering measured data for contaminated media, rather than applying models to derive exposure concentrations.

The system contains a client-based, chemical-specific database for physicochemical properties required for fate/transport, bioaccumulation factors, and human health effects (i.e., reference doses/concentrations and cancer slope factors). Chemicals can be queried by name or CAS (Chemical Abstracts Service) number. The system links to an on-line (web-based) database for aquatic ecological health effects referred to as the Environmental Residue Effects Database (ERED) (http://www.wes.army.mil/el/ered/index.html). ERED is updated periodically, thus the reason for the on-line linkage, which is seamless allowing effects data queried by species and chemical to be pulled into the system automatically. On-line linkage to a terrestrial ecological effects database of toxicity reference values is being developed during 2002.

2 Example application

An example application is presented to demonstrate several of the software features. This example was kept relatively simple to fit within paper size constraints and represents risk assessment for a hypothetical brownfield site located near a residential area. An adult human is the target receptor for this example, but other receptors could be considered, such as a child. Soil at the brownfield site is contaminated with cadmium as a result of operation of a battery manufacturing plant. The current reasonable maximum exposure (RME) soil concentration of cadmium based upon field sampling and measurement is 1000 mg/kg. Community stakeholders and public health officials want to know the present health risks for a residential area located across the road from the brownfield site.

The exposure routes for this scenario are considered to be soil inhalation (from resuspension), soil ingestion, and soil dermal contact. Groundwater and surface water contamination are not concerns for this site. The following FRAMES modules are required for this application: source term, human exposure, human receptor, and human health impacts. The FRAMES object workspace representing this scenario is shown in Figure 1. A known or specified source model is used for the source module, and each of the other three modules contains MEPAS models that were used for this example. The model parameters used for each of the MEPAS models are shown in Table 1. The soil concentration is assumed to be constant, i.e., no decay or leaching. Since there are few toxicity reference values for dermal contact, the MEPAS health impacts model uses the oral reference dose and cancer slope factor along with the GI absorption fraction to calculate dermal reference values per EPA guidance. Dermal reference dose is obtained by multiplying the oral reference dose by the GI absorption fraction, whereas dermal cancer slope is obtained by dividing the oral slope by the GI absorption fraction. Health impacts for this example are shown in Table 2 in terms of noncarcinogenic hazard index (HI) and carcinogenic cancer risk. Health impacts are reported for each exposure route and combined routes. An example like this can be set up and run very quickly (on the order of minutes to about an hour, depending on the user's experience and familiarity with the system).

3 Conclusions

ARAMS is being developed as a versatile tool for conducting screening-level or more focused assessments for both human and ecological health impacts. Although a simple example was presented here, far more complex assessments can be conducted. For example, in the case presented here, one could model a time varying source released to the vadose zone with decay and leaching, thus producing time-varying exposure concentrations, doses, and health impacts, allowing assessment of future health risks. Other environmental pathways could have been included too, such as air, groundwater, surface water, and food. Other receptor exposure routes could have been included as well, such as: water contact, ingestion, and inhalation during showering; air inhalation; and ingestion of contaminated food.

The object workspace enables the user to conceptualize the problem making assessments more intuitive. Also, the system is modular, which facilitates the addition of new models, databases, and assessment methods. ARAMS has been recently adapted to provide the capability to conduct tier 1 (or level 1) ecological assessments, which will be the topic of another paper. The tier 1 ecological assessments consider hazard quotients (i.e., body concentrations or exposure doses divided by toxicity reference values) without considering spatial aspects, such as home range, habitat use factors, etc. Tier 2 assessments will consider spatial aspects. Additionally, there are plans for considering species population risks.

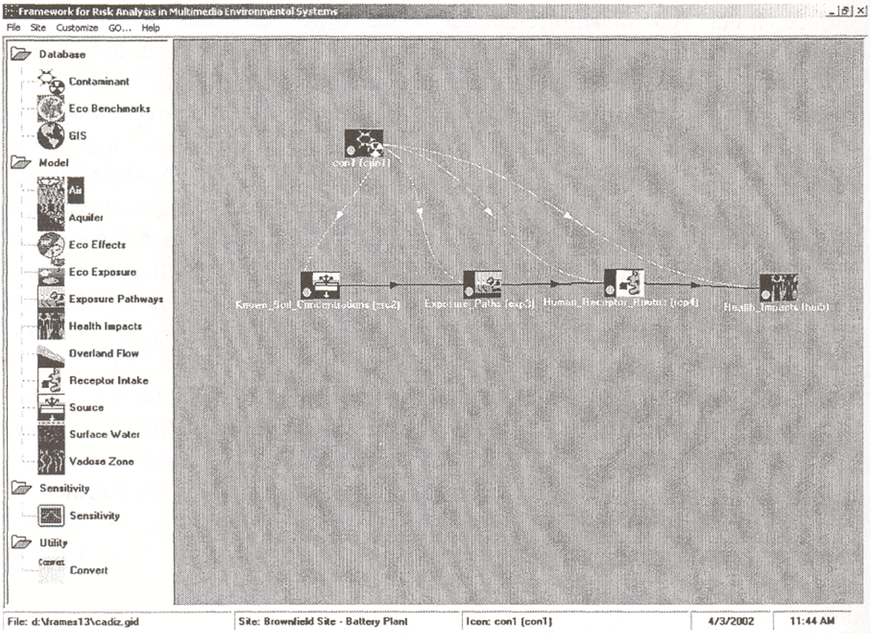

Figure 1. Object workspace for example application

Table 1. Input parameters for example case		
Model/Parameter	Units	Value
Exposure: soil leach rate	cm/yr	0
Exposure: airborne particulate mass loading factor (mass of soil that is suspended in the air above the contaminated soil)	kg/m^3	1×10^{-7}
Receptor: body weight	Kg	70
Receptor: exposure duration	Years	30

Table 1. Input parameters for example case, continued		
Model/Parameter	Units	Value
Receptor: skin area	cm^2	5800
Receptor: soil adherence factor	mg/cm^2	1.0
Receptor: frequency of soil dermal contact	events/day	1
Receptor: fraction of year that soil dermal contact occurs	unit-less	1
Receptor: soil ingestion rate	g/day	0.1
Receptor: fraction of year that soil ingestion occurs	unit-less	1
Receptor: inhalation rate for resuspended soil	m^3/day	20
Receptor: fraction of year that resuspended soil inhalation occurs	unit-less	1
Contaminant database: dermal absorption fraction for soil	unit-less	0.001
Contaminant database: Gastrointestinal absorption fraction, insoluble	unit-less	0.01
Contaminant database: inhalation reference dose	mg/kg/day	2.6×10^{-4}
Contaminant database: oral reference dose	mg/kg/day	0.001
Contaminant database: inhalation cancer slope factor	$(mg/kg/day)^{-1}$	6.1

Table 2. Health impacts for example case

Exposure route	HI	Cancer risk
All routes	9.83	7.44×10^{-5}
Soil ingestion	1.43	NA
Soil inhalation	0.11	7.44×10^{-5}
Soil dermal contact	8.29	NA

NA – Not applicable, i.e., cadmium is considered by weight of evidence to be carcinogenic for inhalation only.

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